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U.S. NAVAL AIR MATERIAL CENTER

P H I L A D E L P H I A ,   P E N N S Y L V A N I A

AIR CREW EQUIPMENT LABORATORY

PROBLEM ASSIGNMENT NO. C12RMA52-16, PART 6
DETECTABILITY OF NAVAL AIRCRAFT BY VISUAL MEANS,
MEASURES TO INCREASE OR REDUCE; DEVELOPMENT OF

Aircraft Detectability and Visibility:
V. Detectability of Stimuli Coated with Fluorescent and Ordinary Paints, A Further Study

NAMC-ACEL-470 2 FEBRUARY 1962

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Philadelphia, Pennsylvania

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AIRCRAFT DETECTABILITY AND VISIBILITY:

V. Detectability of Stimuli Coated with Fluorescent and Ordinary Paints, A Further Study

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by

Applied Psychological Services
Wayne, Pennsylvania

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Stimuli and tower

PHOTO NO: CAN-338832(L)-8-61

ABSTRACT

The detectability of various stimuli was investigated by Applied Psychological Services, in collaboration with the Air Crew Equipment Laboratory, in order to provide necessary information for increasing aircraft detectability by visual means. The experiments, conducted in a field visual range situation, involved the following stimuli: fluorescent yellow-orange, fluorescent red-orange, fluorescent red-orange with a white medial stripe, ordinary orange (approximating international orange), white, and white with a black medial stripe. The results indicated that the fluorescent yellow-orange stimulus was the most visible under the three meteorological (sky background) conditions involved. The mean threshold data over the three meteorological conditions suggested the following hierarchical order of detectability for the six stimuli: fluorescent yellow-orange, fluorescent red-orange, white, fluorescent red-orange with a white medial stripe, white with a black medial stripe, and ordinary orange.

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CHAPTER I

INTRODUCTION, BACKGROUND, AND PURPOSE

Introduction

This study forms a part of an ongoing program, conducted by Applied Psychological Services in collaboration with the Air Crew Equipment Laboratory of the U. S. Naval Air Material Center, to investigate methods for increasing or reducing the detectability of aircraft by visual means. A previous study in this program investigated, in a field visual range situation, the detectability of pigmented and achromatic stimulus objects viewed against clear and cloudy sky backgrounds (Siegel, 1961). Although the results of that study were indicative of optimal paint schemes for aircraft detectability purposes, one of the conclusions presented was that "... considerably more validatory studies are required..." (p. 29). The present study represents an extension of the previous work in accordance with that conclusion and recommendation. A greater number of subjects, larger targets, more varied background conditions, and longer viewing distances (increased atmospheric attenuation) were employed in the current extension of the previous work. Hence, the current study not only serves as a cross-check on that work but also acts as an extension of the findings.

Background

At the outset of the present series of studies, a laboratory approach was taken. In these studies, visual laboratory methods were employed in order to obtain comparative data on fluorescent and ordinary paints. The results of these laboratory studies suggested, at least for the fluorescent and ordinary paint samples employed, that: (1) fluorescent paints yielded larger average visual fields (Siegel and Crain 1960), (2) the photochromatic (achromatic) interval was less for fluorescent pigments, (3) fluorescent red-orange possessed a lower tachistoscopic threshold than fluorescent yellow-orange and ordinary orange possessed the lowest threshold of the three, (4) fluorescent pigments possessed lower color thresholds (but not lower object thresholds) than their ordinary paint counterparts (Crain and Siegel, 1960), (5) a single, closed, squarelike stimulus possessed greater effectiveness than any of several other shapes tested, and (6) the effectiveness of a dichromatic stimulus was greater than that of any of its monochromatic elements taken individually (Siegel and Crain, 1961).

In the field investigation, conducted during the winter of 1960, these laboratory findings were generally substantiated with the exception that in contrast with the laboratory findings, the field test suggested that a combined fluorescent red-orange stimulus with a white medial stripe was superior to a solid fluorescent red stimulus of equal pigmented area. The field study also indicated that, with a clear winter sky background, fluorescent yellow-orange, fluorescent red-orange, and ordinary orange (approximating international orange) respectively, were hierarchically ordered in terms of detectability. On the other hand, ordinary orange rose to a high ranking when a cloudy sky background was involved. White, which ranked highest for the clear sky background condition, fell to the lowest possible ranking in the overcast sky condition.

Purpose

The specific purpose of the present study was to measure the comparative detectability of various fluorescent and ordinary paint colors. The experiments were conducted under a variety of meteorological and background viewing conditions in order to achieve results which, at least to a degree, may be generalized. The second specific purpose of the present study was to check the results of previous studies which investigated the detectability of fluorescent and ordinary paint stimuli.

Study 2

In addition to the techniques and methods used to investigate the detectability of fluorescent and nonfluorescent stimuli in the major study here reported, a substudy was performed to investigate the comparative effectiveness of the same stimuli when a different research procedure was employed. The results of this substudy are treated separately and are referred to as Study 2.

CHAPTER II

STIMULI, APPARATUS, PROCEDURES, AND SUBJECTS

Stimuli and Apparatus

The selection of the six stimuli chosen for use in the current study was based largely on the results and suggestions of previous studies performed by Applied Psychological Services (Siegel and Crain, 1960; Crain and Siegel, 1960; Siegel and Crain, 1960; Siegel, 1961), the Medical Research Laboratory (1955), and Blackwell (1960). The six samples employed were: (1) fluorescent yellow-orange, (2) fluorescent red-orange, (3) white, (4) fluorescent red-orange with a white medial stripe, (5) ordinary orange (approximating international orange), and (6) white with a black medial stripe.

The chromatic stimuli were prepared from color samples furnished by the A. Wilhelm Company, Lawter Chemicals, Inc., Switzer Brothers, Inc., and the Radiant Color Company.

Siegel and Crain (1961) suggested that squarelike stimuli possess a detectability advantage; accordingly, square stimuli were used in the present study. Each stimulus was five inches square. Two of the six stimuli were composed of two colors. These were the fluorescent red-orange with a white medial stripe and the white with a black medial stripe stimuli. The fluorescent red-orange and white stimulus consisted of two fluorescent red-orange rectangles (5" long and 1-11/16" wide) separated by a white rectangle (5" long and 1-11/16" wide). The white and black stimulus was composed of two white rectangles (5" long and 1-11/16" wide) separated by a black rectangle (5" long and 1-11/16" wide). The six stimuli described above were mounted on a hexahedral structure by means of magnets. When the stimuli were mounted on the structure, they filled the 1 o'clock, 3 o'clock, 5 o'clock, 7 o'clock, 9 o'clock, and 11 o'clock positions, as shown in Figure 1.

The experiment was performed out-of-doors under natural illumination. In order to assure an unobstructed sky background for a subject viewing the stimuli, the hexahedral structure containing the stimuli was attached to a metal support pole which was mounted on a tower 23 feet high especially constructed for this experiment. This situation is shown in the Frontispiece of this report.

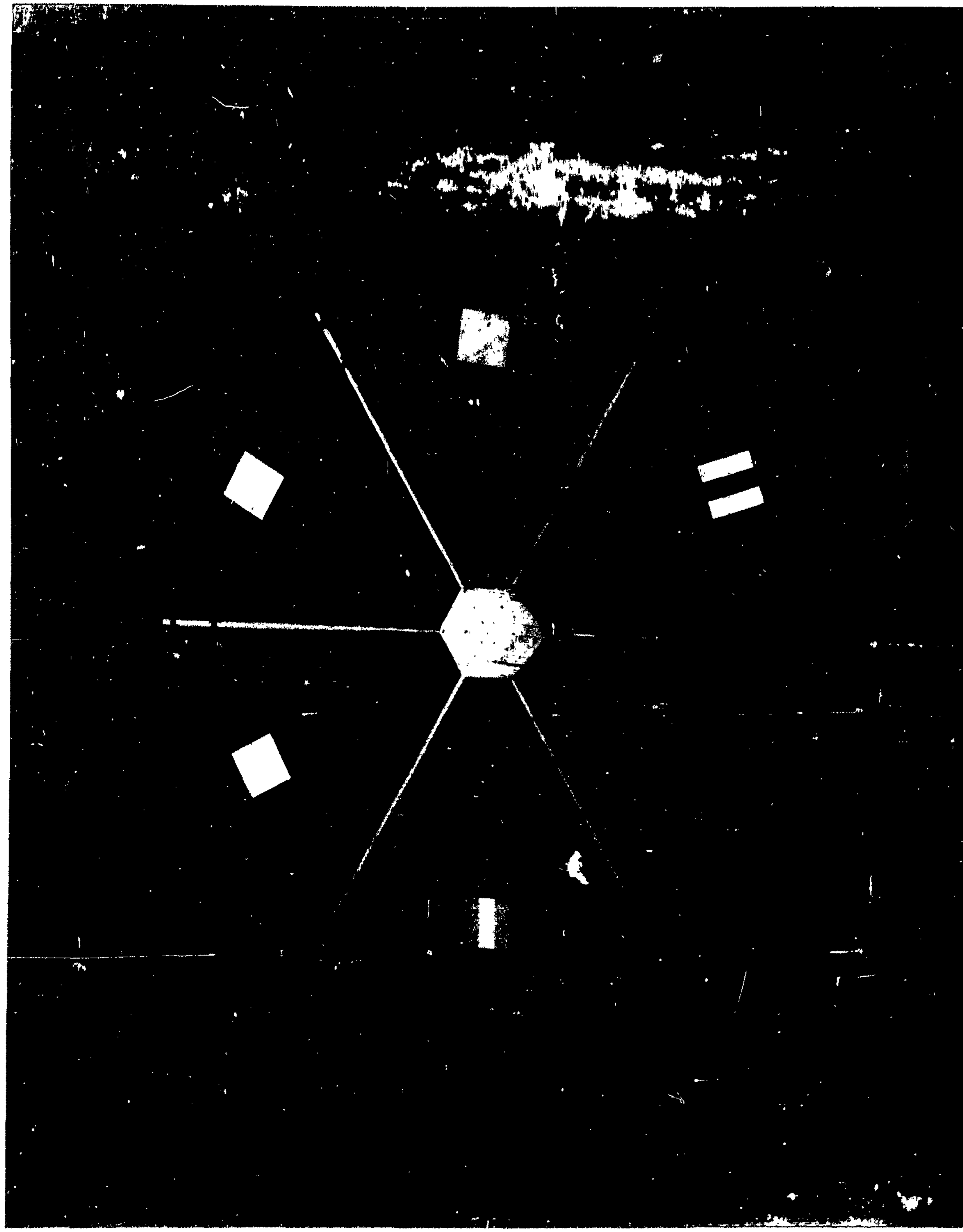

Figure 1 Method of mounting and presenting stimuli

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Procedures

Object and color thresholds were obtained for each stimulus. These were defined in the following manner: (1) object threshold--the maximum distance at which the various stimuli could be detected with certainty, (2) color threshold--the maximum distance at which the various colors could be identified. In all cases, the distance recorded was ground distance measured to the nearest foot.

The subject was seated alongside the driver in an open automotive vehicle (Figure 2) which could be driven at very slow speeds. The vehicle was taken to a viewing distance which rendered the stimuli subliminal and then was driven toward the tower containing the stimuli. The subject was asked to report each stimulus and its clock position as soon as he detected it (object threshold). Travel toward the tower was then continued until the points at which the colors of the objects could be identified (color threshold)*.

The stimuli were presented, en masse, to each subject a total of 12 times in each of three meteorological conditions. The order of presentation and the position of the stimuli were counterbalanced so that each stimulus appeared in each of the six clock positions once in each set of six trials and never appeared between the same two stimuli more than once in each set of six trials.

The object and color thresholds were recorded by an experimenter who was seated in the back of the vehicle. The distance traveled by the vehicle from a known starting point until each threshold point was measured on Rolatape Measuring Wheel, Model 400, which was attached to the rear of the vehicle (Figure 3). The readings so obtained were subsequently converted to distances from the stimuli.

* A check on this decreasing distance procedure was performed in order to determine whether an increasing distance technique would yield different results. In the former case, an error of anticipation might occur; in the latter case, an "inertial" error might be in effect. For two of the thirteen subjects, additional data were collected under conditions in which an increasing distance technique was used. In these check runs, the subjects were started at a distance from which they could clearly see all the stimuli. They were then driven further away from the stimuli reporting, along the way, the points at which the various stimuli faded from sight. The results of this check indicated that no difference existed between the relative hierarchical object threshold order yielded by the two approaches.

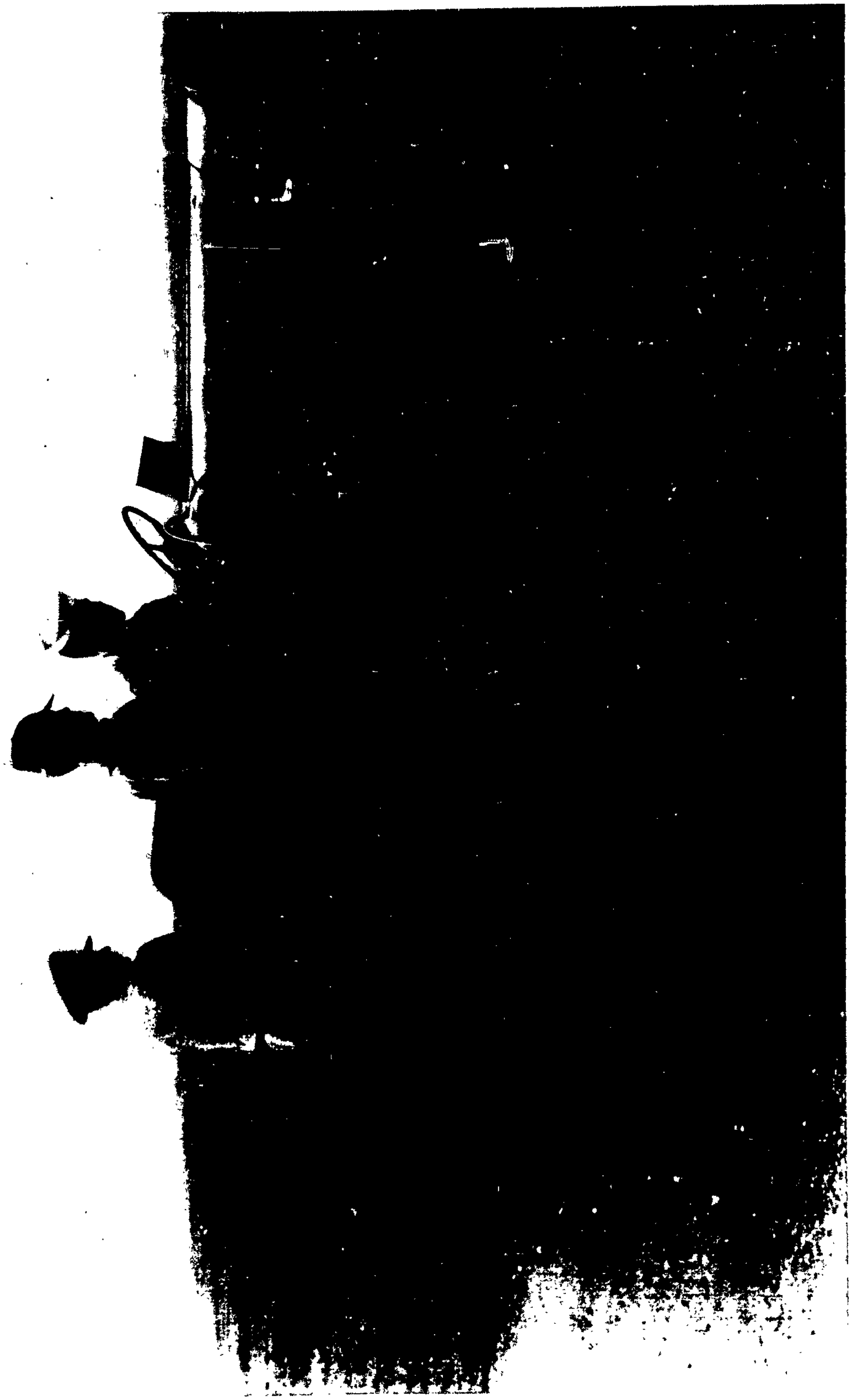

Figure 2 Vehicle for transporting subjects

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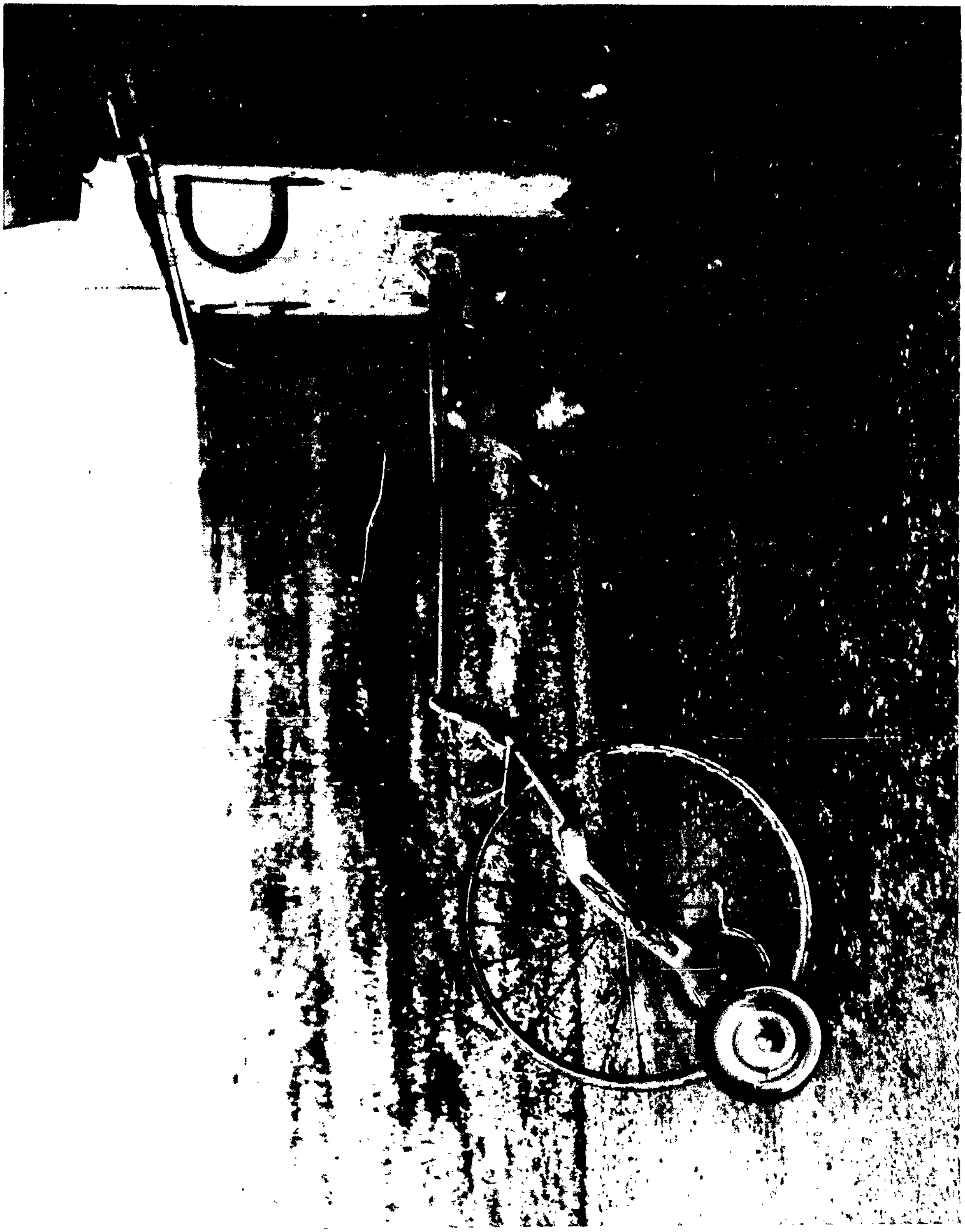

Figure 3 Distance measuring device

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After the subject identified the colors of all six stimuli, he was returned to a suprathreshold distance and was then ready for the next trial. While the subject was being taken back to the starting position, another experimenter stationed on the tower changed the positions of the stimuli. Each trial took approximately eight to ten minutes.

After the sixth trial, the subjects were allowed a rest period which lasted approximately 15 minutes.

Figures 4, 5, and 6 show the stimulus situations as they appeared to the subjects at distances of 1,320 feet, 2,640 feet, and 3,960 feet respectively.

Meteorological (Experimental) Conditions

The stimuli were viewed under three different conditions: (1) sunny A.M., (2) sunny P.M., and (3) cloudy.

The data were collected during the summer months of 1961. In the sunny A.M. condition, the sky background was clear, blue, and without clouds or haze. In this condition, the subjects were tested during the morning between the hours of 9:00 A.M. and approximately 11:30 A.M. During this time interval, the path of the sun's travel was parallel to and in the same direction as the subject--from east to west. At the outset of the trials, the sun was about 35° high and at the conclusion, it was about 75° high. Thus, it was always in front of the stimuli and shining on the stimuli. The stimuli were always in a clear and unobstructed viewing position, without clouds in the background.

The experimenter on the tower took brightness measurements of the sky background and the four monochromatic stimuli at three different times over the course of the 12 trials of each subject. The brightness readings, taken on a spectra spot brightness meter, were made at the beginning of the first trial, the end of the sixth trial, and the beginning of the twelfth trial. The mean brightness measurement for the sky background under this condition was 1,967 foot-lamberts. The United States Weather Bureau station at the Philadelphia International Airport (about four miles away) reported visibility varying from four miles to eight miles during the times that the measurements were made. The Weather Bureau also reported wind velocities varying from five miles per hour to thirteen miles per hour.

Figure 4 Stimulus appearance--1,320 feet

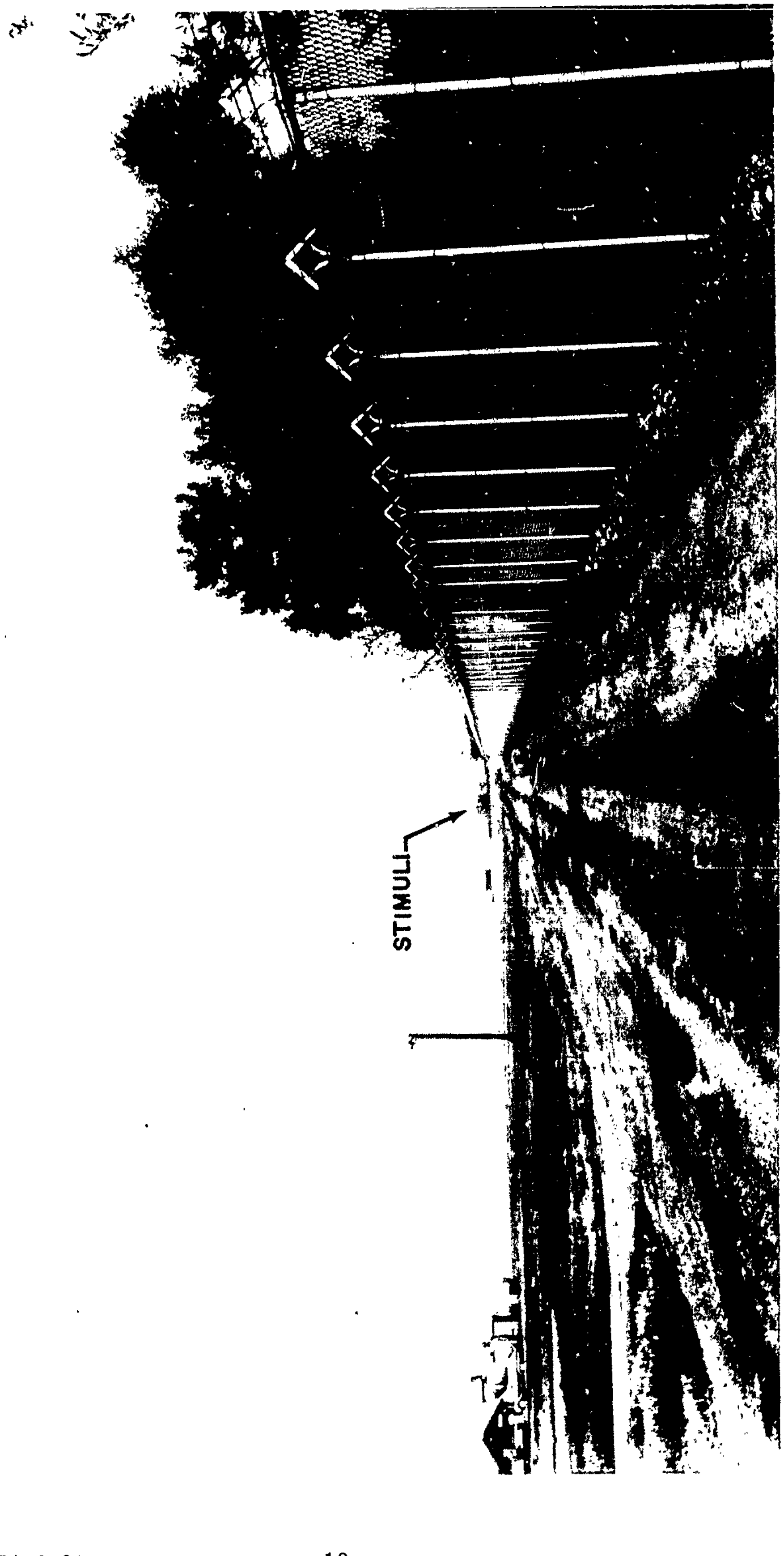

Figure 5 Stimulus appearance--2,640 feet

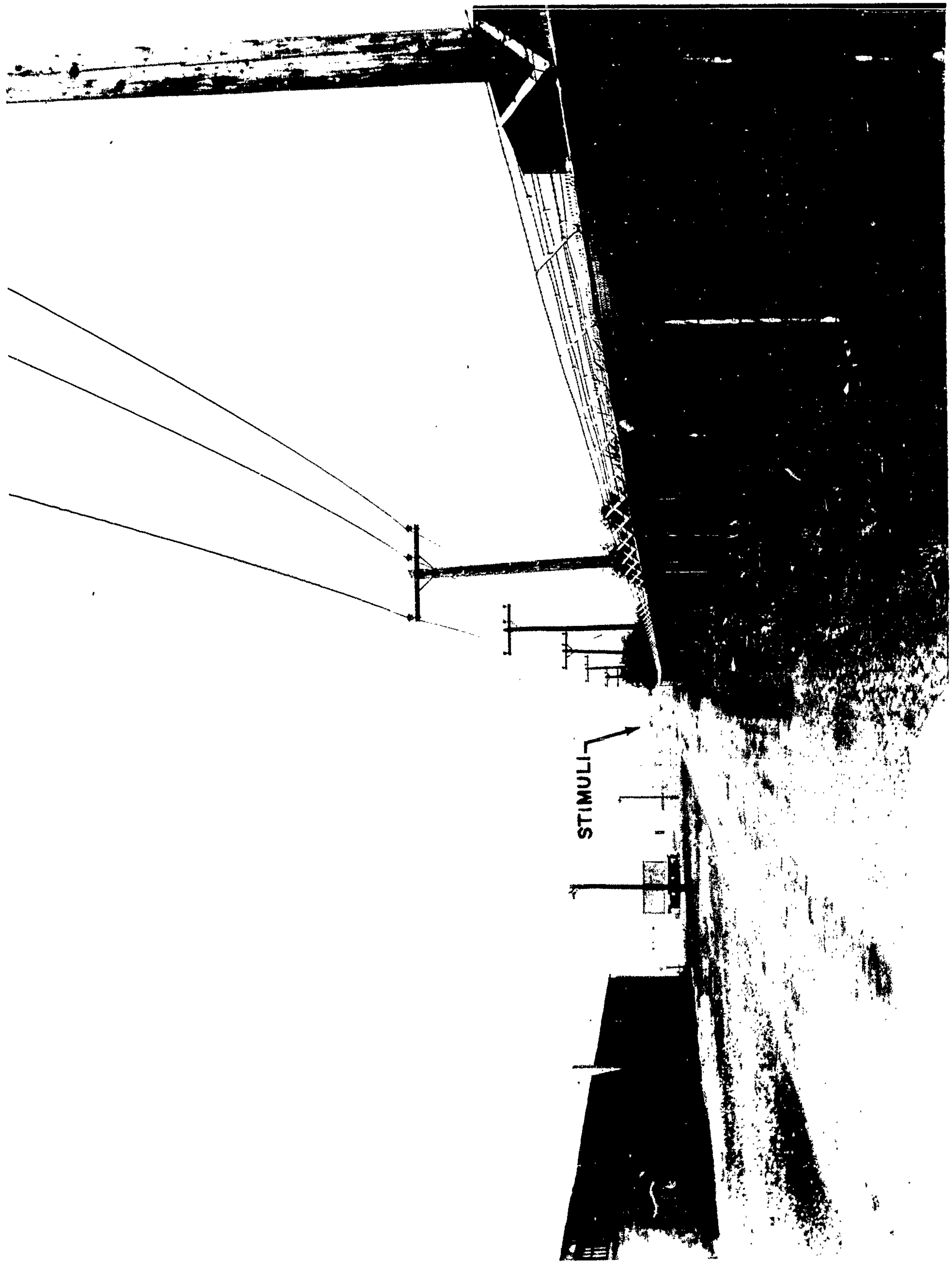

Figure 6 Stimulus appearance--3,960 feet

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The data collected and classified under the sunny P. M. condition were taken between the hours of 1:30 P. M. and 4:00 P. M. During these hours, the position of the sun ranged from almost directly over the stimulus tower (90^{o}) to behind the tower (125^{o}). The mean brightness measurement for the sky background under this condition was 4, 342 foot-lamberts (compared with the mean value of 1, 967 foot-lamberts for the sunny A. M. condition). The sky background for the sunny P. M. condition may be described as clear and blue with no smoke or clouds, but with a slight degree of haze. The Weather Bureau reports visibilities from two and twelve miles, with wind velocities from six miles per hour to fourteen miles per hour for the various days on which these data were collected.

The third meteorological condition considered in this study, the cloudy condition, had a sky background heavily laden with smoke and haze and complete dense gray to gray-white cloud coverage; the sun was completely hidden in this condition. The visibility reported by the Weather Bureau varied from three-fourths mile to ten miles, with wind velocities varying from five to seven miles per hour. The data collected under the cloudy condition were taken during the morning hours of 9:00 A. M. to 11:30 A. M. The mean brightness of the sky background in this condition, 1, 600 foot-lamberts, was considerably lower than for the other two meteorological conditions.

Subjects

All subjects used in this study were enlisted men in the U. S. Navy assigned to duty at the Air Crew Equipment Laboratory. The subjects were screened on the basis of visual acuity and color vision integrity. None suffered from any form or color blindness and all subjects possessed either 20/20 vision or wore corrective lenses rendering their corrected vision at 20/20.

Five subjects served under the sunny A. M. condition*, four subjects were tested under the sunny P. M. condition, and four subjects were involved in the cloudy condition. A total of thirteen subjects were used, of which three subjects were tested under two different conditions.

* Actually, six subjects were tested in this condition. However, the data for one subject were subsequently disregarded in the analysis of results.

All experimental work was conducted at Mustin Field of the Philadelphia Naval Base. A straight, level road at the edge of the field was used. The stimulus tower was placed at the far west end of the road. The path of the vehicle carrying the subjects was always from east to west until the object and color thresholds were obtained.

Study 2

Immediately following the rest period which came after the sixth trial, Study 2 was conducted. In Study 2, a somewhat different experimental procedure was employed. One-half the range of the six object thresholds that had been collected to this point was calculated for each stimulus. After the stimuli had been placed in their appropriate positions on the hexahedral structure, the subject was taken to each of the six calculated positions. He was instructed to look up at the wheel and without studying the stimuli, to call off the stimuli and, if possible, the colors he could identify starting from the one o'clock position and going around the clock to the 11 o'clock position.

CHAPTER III

RESULTS AND DISCUSSION

The obtained mean object and color threshold data were plotted by subject and condition. Visual analysis suggested that a lawful and systematic trend was apparent across all but one subject. Further investigation suggested that the data obtained from this subject were subject to accuracy doubt for several reasons. Accordingly, the data for this subject were eliminated from the subsequent analyses. The data reported in subsequent sections of this chapter are grouped data. However, it can be stated that good relative agreement was obtained among the individual subject means. Thus, it is felt that the grouped data reported do not obscure any individual idiosyncrasies.

Object Thresholds

The mean object threshold across subjects for each condition and stimulus is presented as Table 1. All threshold data are reported in feet from the stimulus.

Table 1

Mean Object Threshold (in feet) for Each Condition

Stimulus	Sunny A. M.	Cloudy	Sunny P. M.
Fluorescent yellow-orange	3,404	2,372	1,996
Fluorescent red-orange	3,298	2,277	1,994
White	3,202	2,122	1,775
Fluorescent red-orange with a white medial stripe	2,927	2,105	1,917
White with a black medial stripe	2,702	1,712	1,900
Ordinary orange	2,354	1,834	1,978

The mean object threshold across conditions and over all subjects is presented for each stimulus as Figure 7 (upper curve). Table 2 summarizes an analysis of variance performed on the individual trial (run and condition) object threshold data. The results of the variance analysis suggest that statistically significant differences exist among the six stimuli and the three meteorological conditions. The stimulus by condition interaction is also significant. In order to assess the individual mean object threshold differences among the six stimuli and the three meteorological conditions, Tukey's gap test was applied. At the .05 level of statistical significance, the gap test divided the six stimulus means into three significant groups. These groups are:

1. fluorescent yellow-orange and fluorescent red-orange
2. white and fluorescent red-orange with a white medial stripe
3. white with a black medial stripe and ordinary orange

Similarly, at the .05 level of confidence, the means of the three conditions were divided by the gap test into two significant groups:

1. sunny A.M.
2. cloudy and sunny P.M.

These analyses suggest the relatively superior detectability of the fluorescent yellow-orange (mean object threshold 2,324 feet) and the fluorescent red-orange (mean object threshold 2,256 feet) stimuli and the relative ineffectiveness of the white and black (mean object threshold 2,105 feet) and ordinary orange stimuli (mean object threshold 2,055 feet).

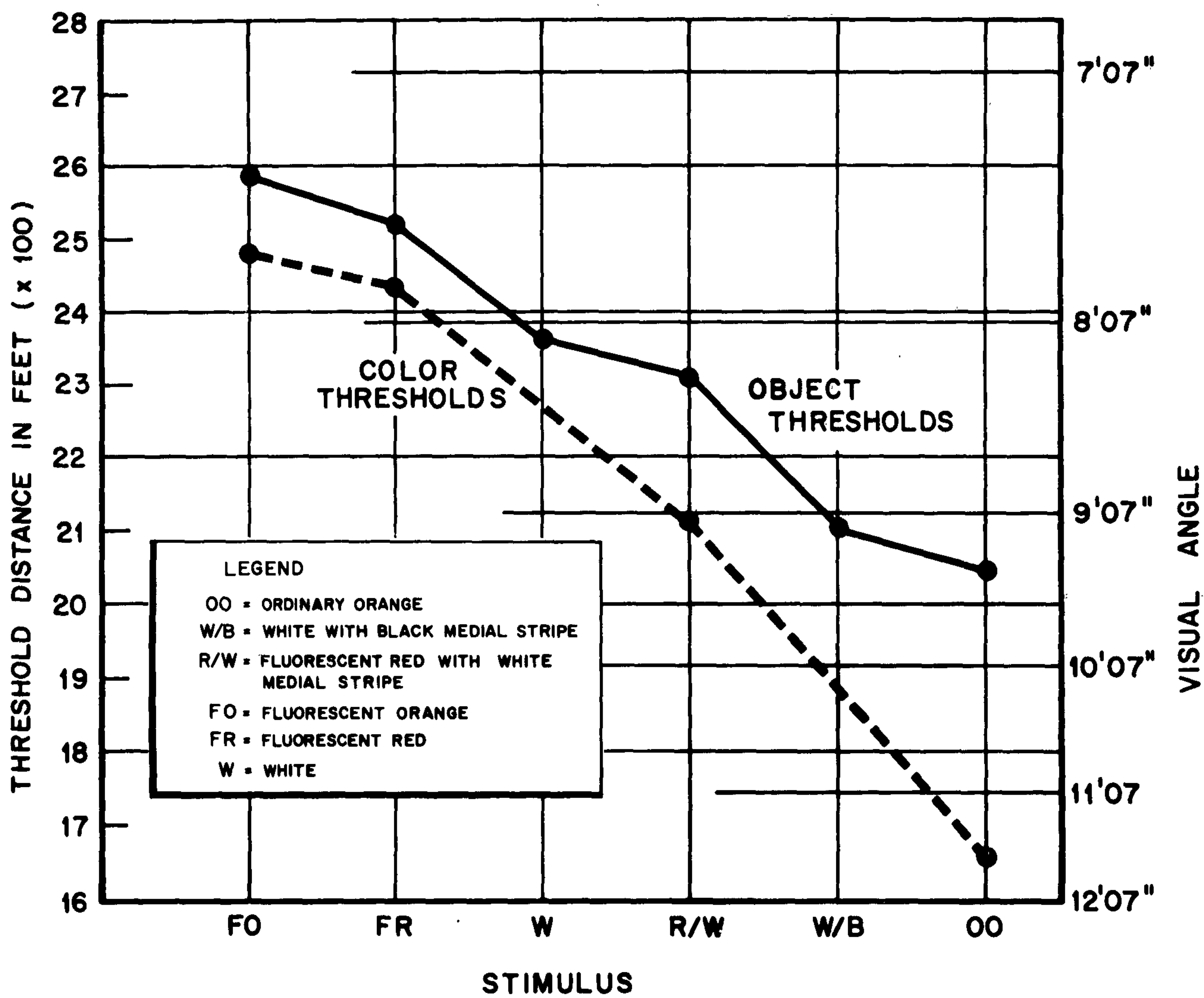

Figure 7 Mean object and color thresholds across meteorological conditions.

Table 2

Analysis of Variance Summary for the Object Threshold Data

Source	DF	SS	MS	F	P
Stimuli	5	40,887,224	8,177,444.80	21.30	.01
Trials	11	3,528,531	320,775.55	.84	NS
Conditions	2	216,898,454	108,449,227.00	282.49	.01
Stimuli x Trials	55	4,392,951	79,871.84	.21	NS
Stimuli x Conditions	10	24,421,834	2,442,183.40	6.36	.01
Trials x Conditions	22	6,480,918	294,587.18	.77	NS
Stimuli x Trials x Conditions	110	7,044,591	64,041.74	.17	NS
Within Cells	720	276,406,505	383,897.92		
Total	935	580,061,008			

Detectability in the sunny A. M. condition was superior to detectability in the cloudy and the sunny P. M. conditions; detectability in these latter two conditions did not differ with statistical significance. The mean object thresholds for each of the meteorological conditions are graphed in Figure 8. Figure 8 suggests the relative maintenance of the hierarchical order of the detectability of the stimuli (with the exception of the white and black and the ordinary orange stimuli in the cloudy condition) plus the interesting phenomenon of "cross-overs" between certain stimuli when going from the cloudy condition to the sunny P. M. condition. This finding is discussed in a later section of this chapter.

Agreement Among Subjects

Analyses were performed on the data in order to determine the degree of relationship among the subjects' mean object thresholds within meteorological conditions. The coefficient of concordance was obtained between the object thresholds of the subjects tested under each of the three meteorological conditions. The resultant coefficients, presented as Table 3, were all significant at the .01 level of confidence. From these coefficients, it is clear that close subject agreement existed on the relative object thresholds of the six stimuli concerned.

Table 3

Coefficient of Concordance Among Subjects' Object Thresholds

Condition	Coefficient of Concordance
Sunny A. M.	.86
Cloudy	.91
Sunny P. M.	.87

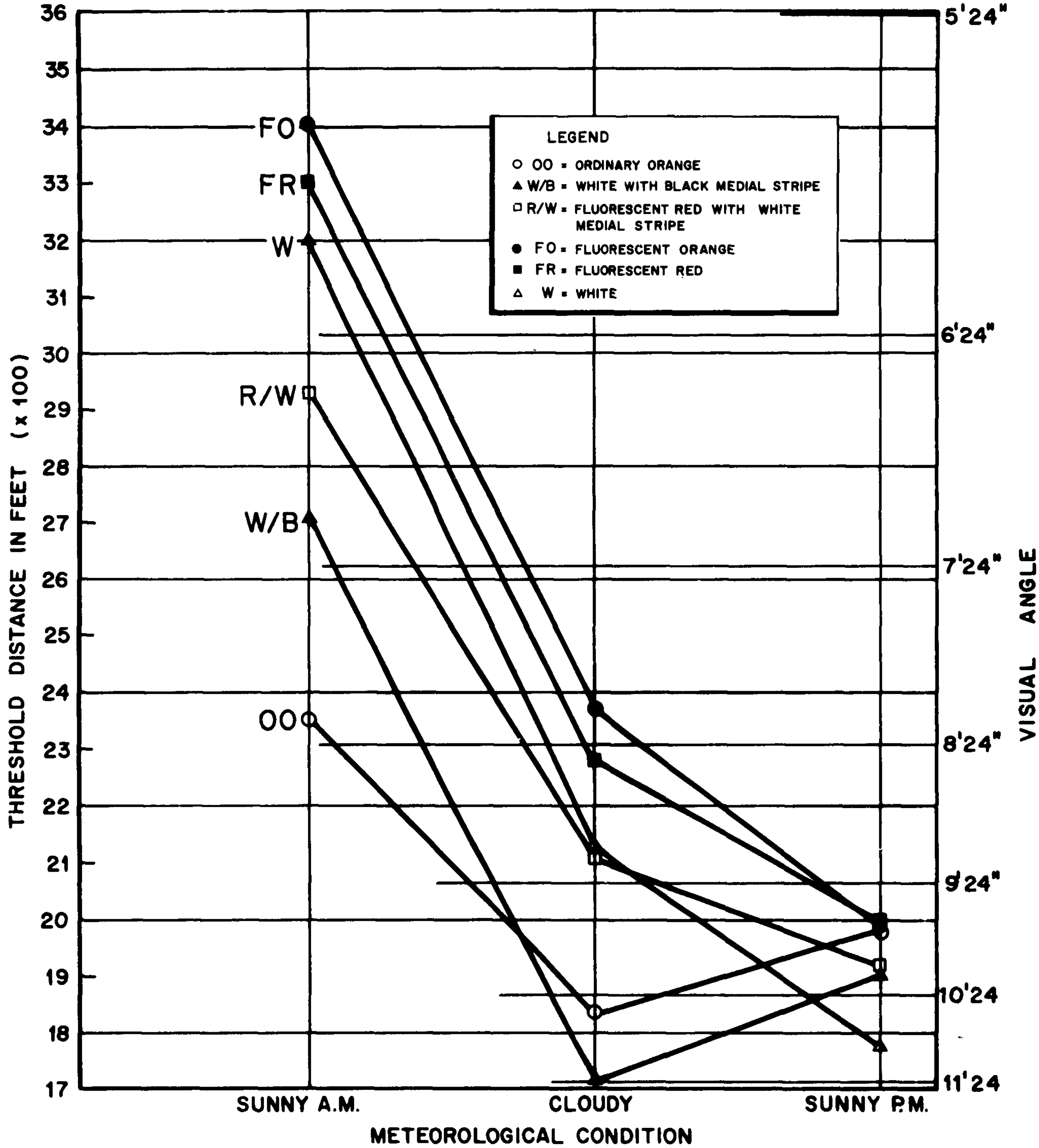

Figure 8 Object threshold (distance) as a function of meteorological condition and visual angle subtended.

Color Thresholds

The color threshold across subjects for each condition and stimulus is presented as Table 4. The obtained mean color thresholds for all three conditions are plotted in Figure 7 (lower curve). An analysis of the variance of the individual subject color threshold data revealed statistically significant differences among the same variables as were found to differ significantly, one from the other, in the analysis of the object threshold data. Specifically significant differences were indicated among the four stimuli (the white and black, and the white stimuli were not considered in this portion of the study), and among the three meteorological conditions. The stimulus by condition interaction was also significant. The results of the variance analysis of the color threshold data are summarized in Table 5.

Table 4

Mean Color Threshold (in feet) for Each Condition

Stimulus	Sunny A. M.	Cloudy	Sunny P. M.
Fluorescent yellow-orange	3,329	2,288	1,829
Fluorescent red-orange	3,270	2,204	1,828
Fluorescent red-orange with a white medial stripe	2,766	1,976	1,472
Ordinary orange	2,174	1,592	1,212

Application of Tukey's gap test revealed three significantly different groups at the .05 level of confidence:

1. fluorescent yellow-orange and fluorescent red-orange
2. fluorescent red-orange with a white medial stripe
3. ordinary orange

The gap test as applied to the meteorological condition means divided the data into three significantly different groups:

1. sunny A. M.
2. cloudy
3. sunny P. M.

Table 5

Analysis of Variance Summary for the Color Threshold Data

Source	DF	SS	MS	F	P
Stimuli	3	72,528,989	24,176,329.67	69.53	.01
Trials	11	2,500,808	227,346.18	.65	NS
Conditions	2	191,544,397	95,772,198.50	275.42	.01
Stimuli x Trials	33	2,748,109	83,276.03	.24	NS
Stimuli x Conditions	6	6,290,766	1,048,461.00	3.02	.01
Trials x Conditions	22	3,671,612	166,891.45	.48	NS
Stimuli x Trials x Conditions	66	5,196,122	78,729.12	.23	NS
Within Cells	480	166,911,289	347,731.85		
Total	623	451,392,092			

The results of these analyses parallel the results of the object threshold analyses very closely. The fluorescent yellow-orange and the fluorescent red-orange stimuli again possessed the greatest detectability. Similarly, ordinary orange was found to be comparatively inferior. While the object threshold means for the meteorological conditions fell into two significantly different groups, the color threshold means for the meteorological conditions are divided into three significantly different groups. Detectability was again superior in the sunny A. M. condition. Figure 9 presents the mean color thresholds for each condition. Figure 9 suggests that the relative position of each stimulus remains the same for each of the four meteorological conditions.

Agreement Among Subjects

As with the object threshold data, the degree of relationship among the various subjects' color thresholds under each of the three conditions was determined. The coefficients of concordance resulting are presented as Table 6.

Table 6

Coefficient of Concordance Among Subjects' Color Thresholds

Condition	Coefficient of Concordance
Sunny A. M.	.90
Cloudy	1.00
Sunny P. M.	.92

The coefficients presented in Table 6 suggest close agreement among the subjects on the hierarchical order of detectability of the colors of the four stimuli involved.

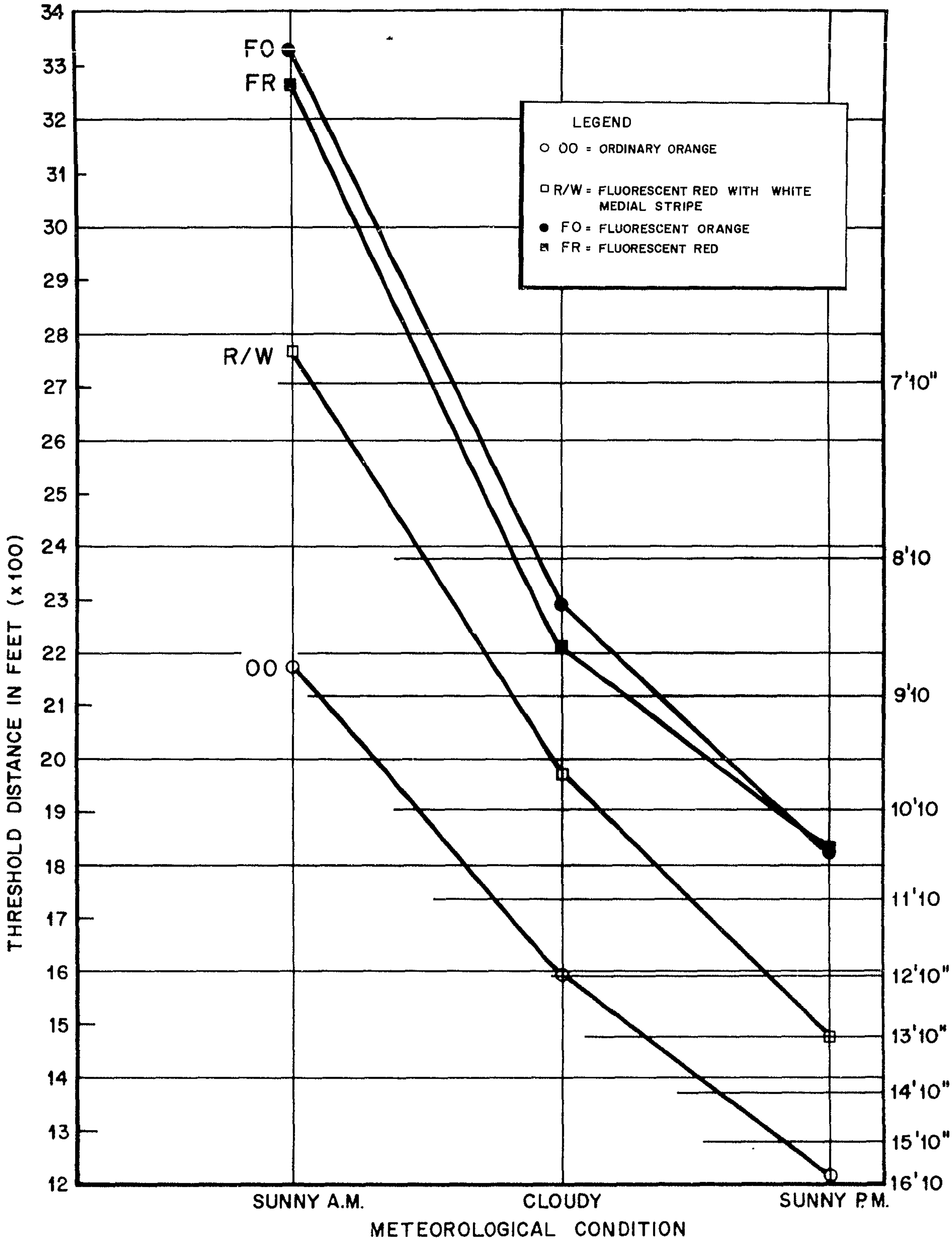

Figure 9 Color threshold (distance) as a function of meteorological condition and visual angle subtended.

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Within Subject Agreement on Object and Color Thresholds

As one might surmise from the foregoing discussion, a comparison of Figures 8 and 9 suggests, with the exception of the sunny P. M. conditions, considerable agreement between the hierarchical order of the object and color thresholds. In order to test the degree of relationship between the hierarchical order of the object and color thresholds, product moment coefficient of correlation for each subject and the average coefficients of correlation for all subjects tested under a specific experimental condition were calculated. These are presented in Table 7.

Table 7

Product Moment Coefficient of Correlation Between Object and Color Threshold for Each Subject

Condition	Subject	r
Sunny A. M.	1	.96
	2	.76
	3	.98
	4	.93
	5	1.00
	Mean*	.96
Cloudy	1	.91
	2	.96
	3	.95
	4	.88
	Mean	.93
Sunny P. M.	1	.12
	2	.15
	3	.15
	4	.13
	Mean	.14

* The means were obtained by converting each r to a z' score, averaging the z's and then converting the obtained mean z' to an r.

Photochromatic Interval

Table 8 presents the differences between the object and color thresholds for each of the four monochromatic stimuli. Under each condition, the ordinary paint sample (orange) had a greater differential between its object and color thresholds than any of the fluorescent paint samples. In two of the meteorological conditions (sunny A. M. and cloudy), fluorescent red-orange possessed the smallest photochromatic interval. In the sunny P. M. condition, the smallest photochromatic interval was demonstrated by fluorescent yellow-orange.

Table 8

Mean Distance Differentials (in feet) Between Object and Color Thresholds

Meteorological Condition	Stimulus	Photochromatic Interval
Sunny A. M.	Fluorescent yellow-orange	75
	Fluorescent red-orange	28
	Fluorescent red-orange with white medial stripe	161
	Ordinary orange	180
Cloudy	Fluorescent yellow-orange	106
	Fluorescent red-orange	84
	Fluorescent red-orange with white medial stripe	238
	Ordinary orange	380
Sunny P. M.	Fluorescent yellow-orange	194
	Fluorescent red-orange	225
	Fluorescent red-orange with white medial stripe	428
	Ordinary orange	820
Mean	Fluorescent yellow-orange	125
	Fluorescent red-orange	112
	Fluorescent red-orange with white medial stripe	276
	Ordinary orange	460

Results--Study 2

Spearman rank correlation coefficients were calculated between the object thresholds described above, and the ranking of the number of times the stimuli were detected at each of the six subject positions at which data were collected in Study 2. The results, as presented in Table 9, suggest that close agreement existed between the two methods of measuring object detectability.

Table 9

Spearman Rank Correlation Coefficients Between the Object Thresholds Reported and the Results of Study 2

Condition	Correlation (rho)	P
Sunny A. M.	.93	.05
Cloudy	.89	.05
Sunny P. M.	.87	.05

Discussion

The brightness of fluorescent stimuli is intensified by the very nature of their pigmentation. Fluorescent colors are said to convert light energy to the dominant wave length involved. The combination of this energy conversion plus the actual luminous reflectance of fluorescent pigments acts to make them appear brighter than ordinary colors. In the present study, and under the conditions involved, the fluorescent colors repeatedly displayed their relative superiority. Fluorescent yellow-orange and fluorescent red-orange, although not differing significantly from each other, were consistently and significantly more easily discernible than the other stimuli involved.

Detection Probability

The object detection probability, for the stimuli and the conditions involved, is plotted as Figures 10, 11, and 12 (the sunny A. M. condition, the cloudy condition, and the sunny P. M. condition, respectively). Figure 10 indicates that the 100% detection probability distance for the fluorescent yellow-orange stimulus under the sunny A. M. condition was 2,925 feet. This figure may be compared to a distance of at least 1,645 feet for a 100% detection probability distance for the ordinary orange stimulus of equal area. In like manner, Figure 11 indicates that 50 per cent of the subjects could detect the fluorescent yellow-orange stimulus at a distance of 2,350 feet, whereas the same percentage of the subjects required 1,950 feet to detect the ordinary orange stimulus.

If the individual meteorological conditions are considered, it is noted that the between stimulus detectability differences become smaller from the sunny A. M., to the cloudy, to the sunny P. M. conditions (the order in which the stimuli generally were most detectable). The differences decreased to the point that for a detection probability of 1.00 under the sunny P. M. condition, a distance of 1,534 feet and 1,533 feet for the fluorescent yellow-orange and ordinary orange stimuli, respectively, were needed (Figure 12).

Visual Angle

Figures 13, 14, and 15 present detection probability as a function of the visual angle subtended. Since visual angle is a function of distance, the smaller visual angles required by the fluorescent stimuli, for any given detection probability, are to be expected. A comparison of the fluorescent yellow-orange and the ordinary orange stimuli in the sunny A. M. meteorological condition (Figure 13) indicates that visual angles of approximately 6'40" and 11'45" respectively are required at the 1.00 detection probability. Figure 13 also indicates that 25 per cent of the subjects required a visual angle of 5'00" in order to detect the fluorescent yellow-orange stimulus. In contrast, a visual angle of almost 5'40" was required by 25 per cent of the subjects in order to detect the ordinary orange stimulus. Figures 14 and 15 present the detection probability for the cloudy and sunny P. M. conditions. In the sunny P. M. condition, only a nominal difference existed between the visual angles needed, at any probability of detection, to detect the fluorescent yellow-orange and ordinary orange stimuli. At P = .25, the visual angles required were 7'55" and 7'57"; at P = .50, they were 9'31" and 9'29". At P = 1.00, they were 12'38" and 12'40".

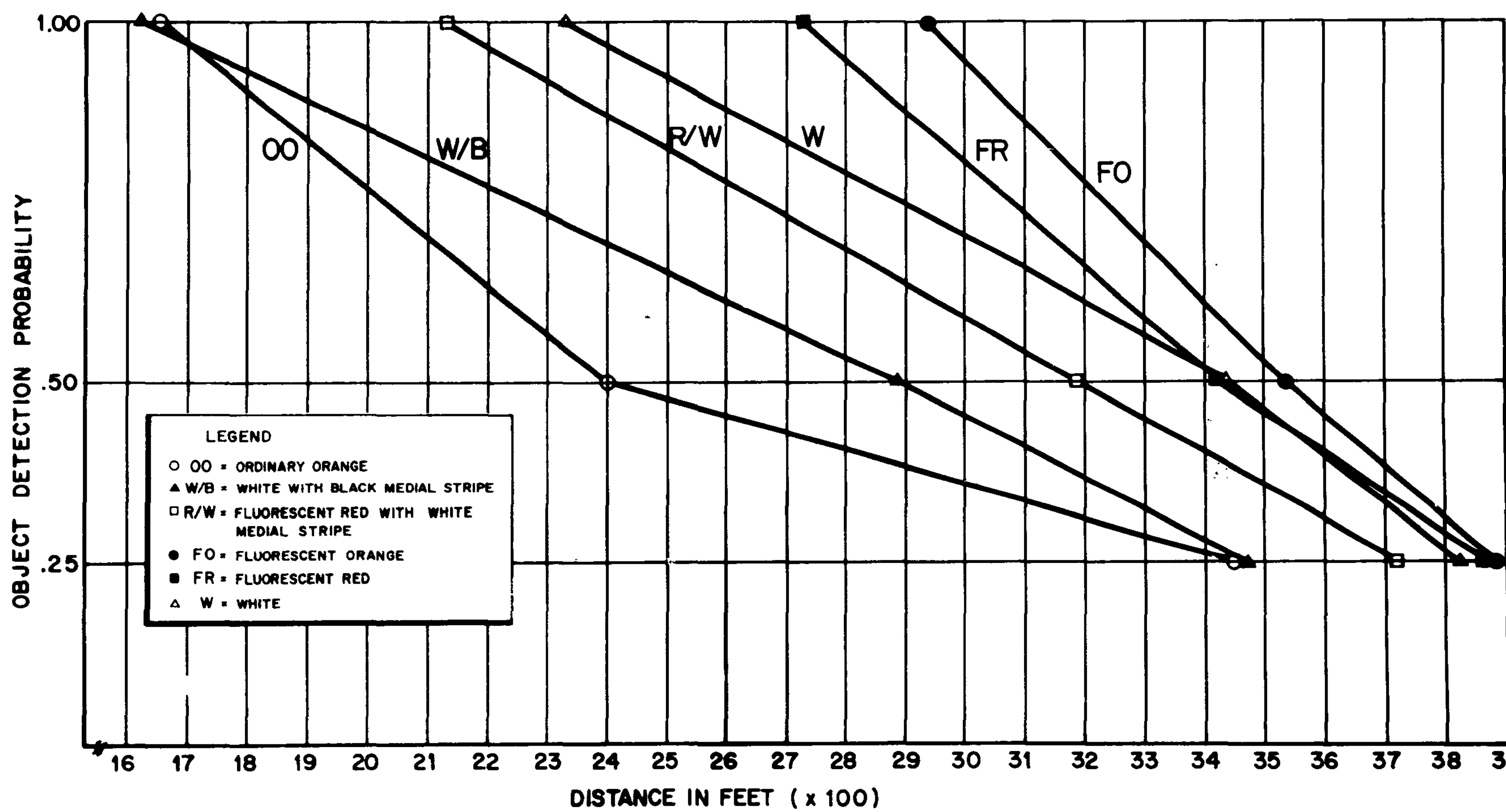

Figure 10 Object detection probability as a function of distance (sunny A.M. condition).

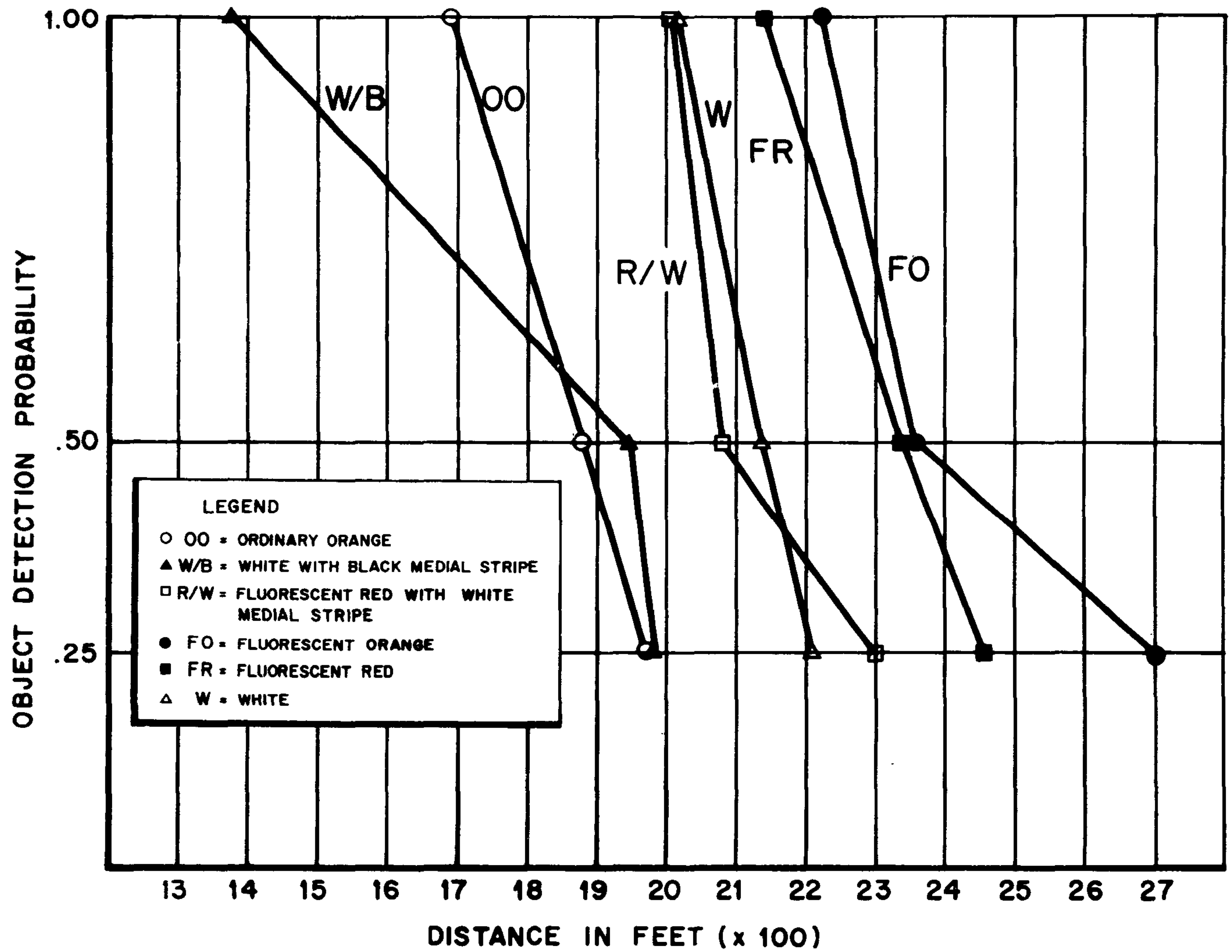

Figure 11 Object detection probability as a function of distance (cloudy condition).

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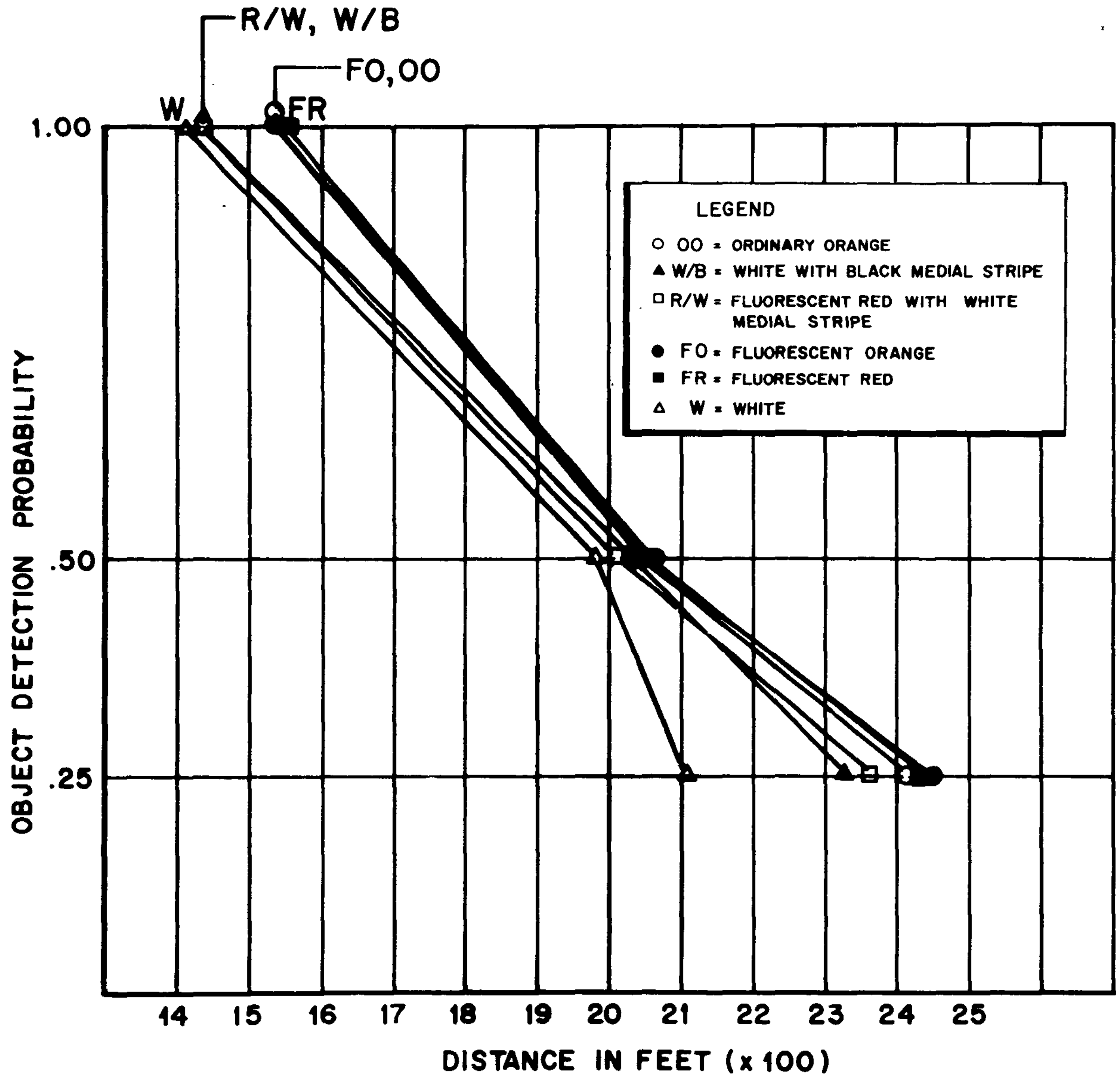

Figure 12 Object detection probability as a function of distance (sunny P.M. condition).

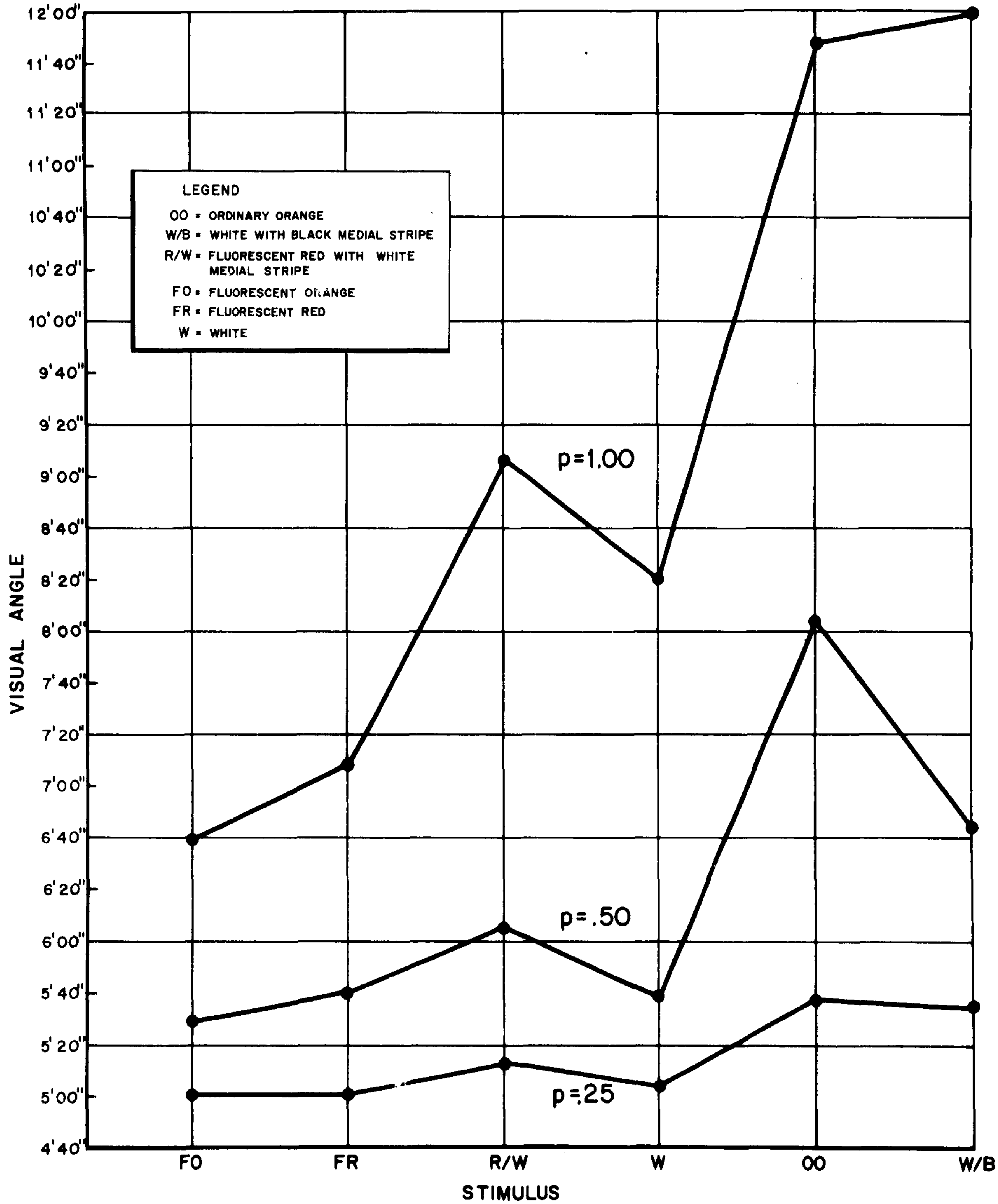

Figure 13 Detection probability as a function of visual angle (sunny A.M. condition).

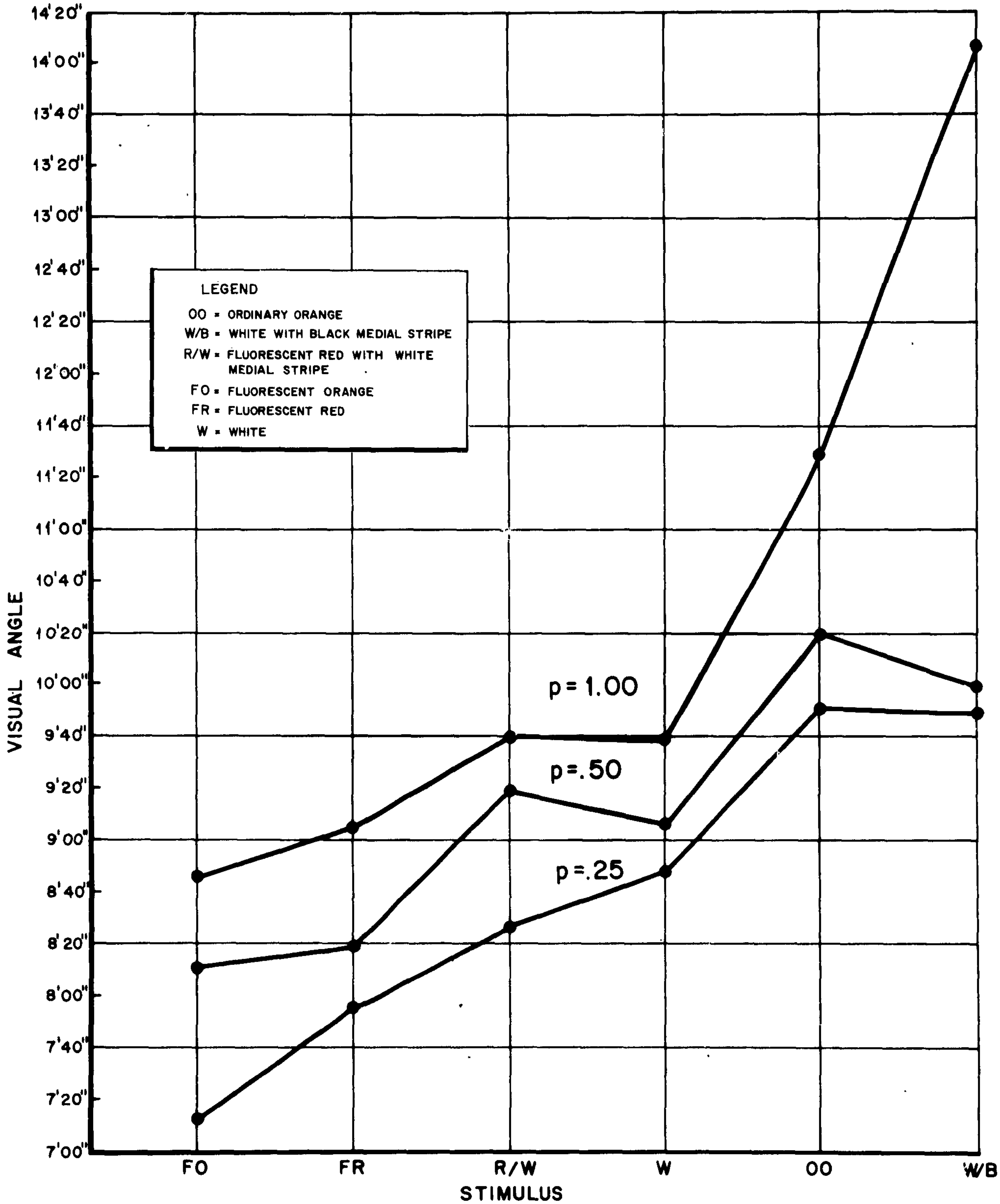

Figure 14 Detection probability as a function of visual angle (cloudy condition).

PHOTO NO: CAN-341512(L)-1-62

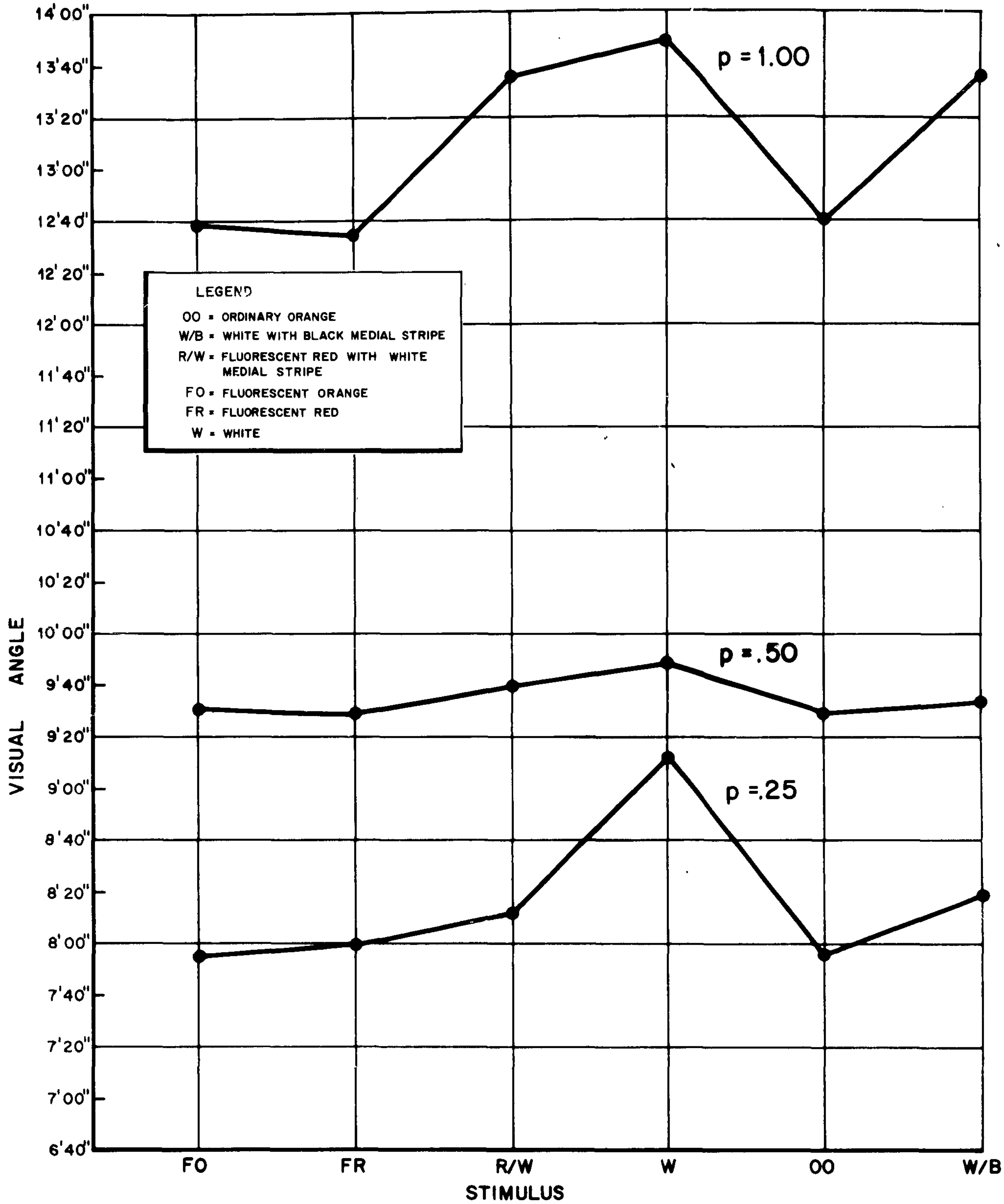

Figure 15 Detection probability as a function of visual angle (sunny P.M. condition).

PHOTO NO: CAN-341513(L)-1-62

Brightness and Chromatic Contrast

Experimental studies in visibility often suggest that brightness contrast (between an object and its background) is an important determinant of stimulus visibility. Blackwell (1960) drew attention to the importance of chromatic contrast in visibility problems involving fluorescent colors. The brightness contrast of each solid stimulus was calculated for each meteorplogical condition. The mean brightness contrasts obtained are presented as Table 10.

Table 10

Brightness Contrast of Stimuli in Various Meteorological Conditions

Condition	Stimulus	Brightness Contrast
Sunny A. M.	White	1.53
	Fluorescent yellow-orange	1.03
	Fluorescent red-orange	.53
	Ordinary orange	.06
Cloudy	White	.57
	Fluorescent yellow-orange	.33
	Fluorescent red-orange	.02
	Ordinary orange	-.29
Sunny P. M.	White	-.33
	Fluorescent yellow-orange	-.38
	Fluorescent red-orange	-.48
	Ordinary orange	-.61
Mean	White	.59
	Fluorescent yellow-orange	.33
	Fluorescent red-orange	.02
	Ordinary orange	-.28

From the brightness contrast data alone, one would expect that since the white stimulus had the greatest contrast with its background for the sunny A. M. and cloudy conditions, it would also show the greatest detectability in these conditions. However, this is not the case. Both of the fluorescent stimuli were significantly more visible than white, indicating the influence of some factor other than brightness contrast alone. Similarly, on the basis of the brightness contrast data for the cloudy condition, the ordinary orange stimulus would be expected to be almost as visible as the fluorescent yellow-orange stimulus and more visible than the fluorescent red-orange stimulus. However, Figure 8 indicates that this was clearly not the case. Ordinary orange was still less detectable than the fluorescent colors or white.

Figure 8 indicated a "cross-over" effect for the ordinary orange, the white and black, and the white stimuli when the cloudy and the sunny P. M. condition were compared. Some explanation for this cross-over may be found in the brightness contrast data. It is noted that in the sunny P. M. meteorological condition, white possessed the smallest brightness contrast. Hence, low detectability may have been expected for the white stimulus in this condition. Ordinary orange, on the other hand, had the greatest degree of contrast (-.61) in the sunny P. M. condition and hence may have demonstrated good detectability (about as detectable as the fluorescent colors). No brightness measurements were performed on the black and white and the red and white stimuli.

The position of the fluorescent red-orange and white stimulus, under each condition, may be explained by assuming that the combination worked in such a way as to desaturate the effect of the fluorescence and consequently render the stimulus relatively ineffective under any atmospheric condition.

A comparison of Figure 8 with Table 10 indicates that certain of the effects may be explained by brightness contrast but, by no means, can the brightness contrast data be employed as a basis for explaining all the results. The chromaticity function, as well as the luminance function, must be considered. Chromatic targets have added detectability as a result of chromatic contrast with their backgrounds.

Chromatic Summation

It is well known that the perceived saturation of a chromatic stimulus varies with the intensity of the stimulus. Raising or lowering the intensity of a monochromatic source around an optimal level causes a corresponding change in the perceived saturation of the source. Even if a stimulus is foveal, all light colors (with possibly the exception of red) are seen as gray if the intensity is low enough. The range over which a colored stimulus is seen as achromatic is called the photochromatic (or achromatic) interval. Similarly, as the area of a colored stimulus is decreased perceived saturation decreases. Color theorists have generally paid little attention to these phenomena.

In the current work, as well as in the previous field study (Siegel, 1961), and in a laboratory study of this program (Crain and Siegel, 1960), the photochromatic interval of fluorescent pigments was found to be less than that of ordinary paint. This finding is in line with expectancy since the fluorescent pigment is supposed to produce saturation amplification. Thus, when the fluorescent stimuli are seen, they are more likely to be seen as colors and to possess a detectability advantage as a function of chromatic contrast.

Comparison with Previous Work

The results of the present experiment appear to be in acceptable concordance with previous work in those cases in which comparisons may be made. Table 11 presents the rank order of the mean object thresholds of the stimuli in the present experiment and the mean visual difficulty, $\tilde{C}$, of the stimuli viewed against a sky background in Blackwell's (1960) experiment.

Table 11

Rank Order of the Mean Object Thresholds of the Present Experiment and the Visual Difficulty, $\tilde{C}$, for the Stimuli Viewed Against a Sky Background in Blackwell's Experiment

Stimulus	Present Experiment: Rank Order of Mean Object Thresholds	Blackwell's Experiment: Mean Rank Order of Visual Difficulty, $\tilde{C}$, for Sky Background
Fluorescent yellow-orange	1	1
Fluorescent red-orange	2	2
White	3	3
Fluorescent red-orange with a white medial stripe	4	not involved
Ordinary orange	6	4
White with a black medial stripe	5	not involved

It is apparent from Table 11 that both studies agree exactly on the hierarchical ordering of the stimuli when the means of all meteorological conditions are considered. Thus, it appears that fluorescent yellow-orange is the most effective color in terms of the greatest detectability values and ease of visibility.

The results of the present study may also be compared with the results of Siegel (1960). Only Siegel's "clear sky" condition is considered here since only once subject was involved in his cloudy sky background meteorological condition. In that study, the object thresholds of square stimulus objects were hierarchically ordered as follows: (1) white, (2) fluorescent yellow-orange, (3) fluorescent red-orange with a white medial stripe, (4) fluorescent red-orange, and (5) ordinary orange (the red-orange and blue stimulus employed in the earlier study is not included in this listing). Concordance between the results of the earlier and the present studies is apparent except for the relative merit of the white and the fluorescent red-orange with a white medial stripe stimuli. The reason for the discrepancy noted is not apparent. However, it is believed that the clear grayish winter sky background of the previous study served to enhance the contrast of the white stimulus (and the white component of the red and white stimulus) in comparison with the brighter (less contrast) summer sky background condition here employed. It is noted that in the sunny P. M. meteorological condition (minimum contrast condition) of the present experiment, white assumed the lowest possible detectability ranking.

The results of Study 2, which were obtained through the use of a method different from that on which the major results are based, add additional veridicality to the findings. The very close agreement between the results of the two different experimental methods suggests that within the conditions here employed, the two techniques yielded relative results which hold across the methods.

CHAPTER IV

SUMMARY AND CONCLUSIONS

This study involved an investigation of the detectability of fluorescent, nonfluorescent, achromatic, and mixed stimuli when viewed under cloudy and sunny meteorological conditions. The sunny condition was further subdivided; in the sunny A. M. condition, the sun's position was in front of the stimuli rendering a positive brightness contrast situation. In the sunny P. M. condition, the background was brighter than the stimuli; hence, a negative contrast situation existed.

The object and color thresholds of thirteen subjects were obtained for the following six stimuli: fluorescent yellow-orange, fluorescent red-orange, white, fluorescent red-orange with a white medial stripe, white with a black medial stripe, and ordinary orange. All stimuli were viewed outdoors under natural viewing conditions. The subjects started each trial at a distance from the stimuli which caused the stimuli to be subliminal and were brought closer to the stimuli until they could detect the stimuli. The distance at which each stimulus could be detected was called the object threshold. The distance from the stimuli was then slowly decreased until the subjects could identify the colors. The distance at which each color could be detected was called the color threshold.

A second or check study, employing a modified technique, was performed to determine the effects of varying research methodology on the resultant data.

The rank order of the mean object thresholds obtained was: fluorescent yellow-orange, fluorescent red-orange, white, fluorescent red-orange with a white medial stripe, ordinary orange, and white with a black medial stripe. This rank order is exactly the same as the rank order of the mean visual difficulty, $\tilde{C}$, presented previously by Blackwell. Fluorescent yellow-orange color was the most easily detectable stimulus under all atmospheric conditions tested.

Correlational analyses were performed to test the agreement between subjects. The correlations indicated substantial agreement among the subjects.

In agreement with Blackwell (1960), it was suggested that brightness contrast alone cannot adequately explain the relative superiority of fluorescent colors. Chromatic contrast was believed to be a powerful contributor to the detectability of the fluorescent stimuli.

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AIR CREW EQUIPMENT LABORATORY

1. Report NAMC-ACEL-470
2. Prob. Assignment No. C12RMA52-16, Part 6

DETECTABILITY OF NAVAL AIRCRAFT BY VISUAL MEANS, MEASURES TO INCREASE OR REDUCE; DEVELOPMENT OF Aircraft Detectability and Visibility: V. Detectability of Stimuli Coated with Fluorescent and Ordinary Paints, A Further Study; by P. J. Federman and A. I. Siegel, 2 February 1962, 48 p.

The detectability of various stimuli was investigated by Applied Psychological Services, in collaboration with the Air Crew Equipment Laboratory, in order to provide necessary information for increasing aircraft detectability by visual means. The experiments, conducted in a field visual range situation, involved the following stimuli: fluorescent yellow-orange, fluorescent red-orange, fluorescent red-orange with a white medial stripe, ordinary orange (approximating international orange), white, and white with a black medial stripe. The results indicated that the fluorescent yellow-orange stimulus was the most visible under the three meteorological (sky background) conditions involved. The mean threshold data over the three meteorological conditions suggested the following

(continued)

hierarchical order of detectability for the six stimuli: fluorescent yellow-orange, fluorescent red-orange, white, fluorescent red-orange with a white medial stripe, white with a black medial stripe, and ordinary orange.

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